The relationship between adolescents' pain catastrophizing and attention bias to pain faces is moderated by attention control

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1. INTRODUCTION

Pain functions to capture attention, motivating avoidance of potential bodily harm [17]. However, when pain is perceived as potentially severe or harmful, individuals may selectively attend to pain and cues for pain over competing demands. Consequently, these individuals may experience increased attentional capture and disruption by pain. This may be particularly true among individuals who catastrophize about pain, characterized by excessive magnification and elaboration regarding the causes and consequences of pain [63]. Indeed, some findings have indicated that attentional capture by pain/pain-related information (termed Attention Bias) is amplified with greater pain-related catastrophizing [12; 23; 28; 48; 49; 51; 57]. However, evidence is not unequivocal; some studies fail to identify expected relationships [13; 26; 41; 54; 56], and others find evidence counter to expectations [6; 58; 59]. These findings suggest that the relationship between attention bias to pain and pain catastrophizing may be moderated by other variables.

Attention control, the ability to focus effortfully in the face of distraction and flexibly shift attention, is likely to be important in understanding the variable relationship between pain catastrophizing and attention bias to pain. This suggestion draws on dual process models - mostly invoked in the context of anxiety disorders [16] - in which anxiety is a consequence of an imbalance between a fast, impulsive responding system, and a regulatory control system. Specifically, attention control has been proposed as an important variable moderating the association between anxiety and attention bias to threat [16; 22; 32; 33; 50]. Studies have indeed revealed that only anxious participants with poor attention control showed an attention bias towards threat. Recently, these findings have been extended to a sample of chronic fatigue patients [25]. However, no studies have investigated such dual process models within the context of pain. Furthermore, there are no studies with younger people, despite the developmental importance of mastery over attention in adolescence [10; 36], and the neurodevelopment of brain regions engaged in goal-directed attention [36; 38; 47]. Indeed, only one published study to date has investigated the relationship between pain catastrophizing and attention bias to pain in a sample of youth, but without considering attention control [62].

Our interest is in the attentional functioning of adolescents with varying levels of pain catastrophizing. We had two objectives. First, to examine the relationship between adolescent pain catastrophizing and attention bias to visual pain stimuli (facial expressions), assessed using dot-probe methodology. Second, to examine the moderating role of adolescents' self-reported attention control on the relationship between pain catastrophizing and attention bias. Based on predictions of the dual process model, we hypothesised that (1) adolescents' level of pain catastrophizing would be positively associated with an attention bias towards pain faces, and (2) self-reported attention control would further moderate the association between pain catastrophizing and attention bias to pain faces such that catastrophizing would relate to attention bias particularly when attention control is low. Additionally, because attention is temporal and dynamic, we presented pain faces at two presentation times, to explore the hypothesised associations at early and later stages of processing.

2. METHODS

2.1 Participants

Participants were recruited from two educational establishments (a senior school and a further education college) in the south of England. Research assistants contacted both educational establishments, and the principals gave verbal consent to make contact with adolescents as potential participants. All participants were completing A-level qualifications (Year 12 or senior year). A teacher at the school contacted all participants, inviting them to take part in the study during regular school hours. We conducted a brief screening with teachers to exclude participants who were suffering from chronic pain. Participants gave written informed consent. We invited eight school classes to take part, 78 adolescents, who all agreed to participate. Exclusion criteria included the presence of visual difficulties or a learning disability. Two participants were excluded from analysis on the basis that they did not complete at least 25% of items on one or both of the questionnaires. Due to technical issues in retrieving recorded dot-probe data, two additional participants were excluded. One participant was excluded from analysis as he had turned 19 by the testing session date.

The final sample entered in the analyses consisted of 73 adolescents (56 girls) aged 16-18 years (*M*= 16.8 years, *SD* = 0.72). The study was approved by the University of Oxford Central University Research Ethics Committee.

<u>2.2 Measures</u>

Adolescents' catastrophic thinking about pain was assessed with the Pain Catastrophizing Scale for Children (PCS-C) [11]. This instrument is adapted from the adult Pain Catastrophizing Scale [49]. The PCS-C also consists of 13 items, and yields a total score that can range from 0 to 52, with higher scores indicating more pain catastrophizing, as well as three subscale scores for rumination (e.g., *"when I am in pain, I keep thinking of other painful events"*), magnification (e.g., *"when I am in pain, I become afraid that the pain will get worse"*), and helplessness (e.g., *"when I am in pain, I feel like I can't go on like this much longer"*). The PCS-C has been shown to be both reliable and valid for children above 9 years [11]. Cronbach's alpha in this study was .93 for the total score.

Adolescents' attention control was assessed with the Attention Control Scale (ACS) [16]. The ACS consists of 20 items, and yields a total score that can range from 20 to 80, with higher scores indicating good attention control. The ACS has two subscale scores for attention focusing (e.g., *''my concentration is good even if there is music in the room around me''*) and attention shifting (e.g., *"It is easy for me to alternate between two different tasks"*). The ACS has shown both good reliability and predictive utility, predicting resistance to interference in Stroop-like spatial conflict tasks as well as attentional disengagement from threat stimuli among highly anxious people [16]. Furthermore, Matthews and colleagues [34] showed greater activation in brain areas related to top-down regulation of emotion (i.e., rACC) in those reporting greater attention control. Attention control has also been measured with good reliability and validity in children [37]. Cronbach's alpha in this study was .83 for the total score.

2.3 Stimulus Materials

The stimulus set consisted of 12 pictures of 6 adult faces (3 male and 3 female). All pictures were drawn from one-second video clips of simulated facial expressions of pain. These pictures were taken from a larger collection of stimuli, previously created and validated in the laboratory by Simon et al. [46], who provided permission for using these stimuli. For these stimuli actors were videotaped while producing neutral facial displays and simulated facial expressions of different pain intensities. For this study, we used neutral facial expressions and facial expressions of moderate pain. We selected facial expressions of moderate rather than severe pain on the basis of evidence that differences in *anxiety*-linked vulnerability may reflect the intensity of stimulus threat required to elicit the attentional vigilance response. That is, whilst strongly threatening stimuli have been shown to universally attract attention as an adaptive mechanism, moderately threatening stimuli are more sensitive to picking up anxiety-linked differences in attentional responding (see [32; 35; 64]). We expected similar findings for pain-related differences in attentional responding, that is, more ambiguous facial expressions would reveal greater variability among individuals. Using these 12 pictures, 6 study slides were generated. Each slide consisted of two pictures of the same adult, presenting a neutral face or a moderate pain face. Using the Facial Action Coding System [18], these video clips were previously reliably coded on occurrence and intensity of facial expression of pain [46]. Furthermore, 2 neutral pictures of 2 other adult faces from the Simon et al. stimulus set were selected to create filler trials which consisted of a neutral-neutral picture pair of the same adult face. Additionally, 2 pictures of 2 other neutral faces used previously by Vervoort and colleagues [62] were selected for the practice trials. The present stimuli have been used in prior research examining attention bias to pain (see [58]). The validity of the present stimulus set used during the experimental phase is supported by previous findings of significantly different observer pain ratings between neutral and moderate pain facial expressions (see [61]).

2.4 Dot-probe task

The dot-probe task measures attention bias by simultaneously presenting a pain-related and neutral stimulus, one of which is then replaced by a dot. Participants are required to make a decision about the location of the dot, and whilst pain-related and neutral stimuli are not critical for responding, attention capture is inferred by speeded reaction times to the dot in a location where a pain-related or neutral stimulus was previously presented.

All stimuli were presented against a black background. Each trial in the dot-probe task began with a 500 ms presentation of a white fixation cross in the middle of the screen. Participants were instructed to fixate their gaze on this location. Then, one picture pair appeared and remained visible for either 100 ms (50% of the trials) or 1250 ms. Each facial image in this pair was 47 mm in width and 78 mm in height. One of the pictures was presented above and one below the fixation cross, with the centre of the pictures positioned 57 mm above and below (respectively) the centre of the screen. Immediately after the offset of these two pictures, a small white rectangle (0.9/1 mm) was presented at the location of one of the pictures (the probe). Participants had to indicate the probe location by pressing one of two buttons as quickly and accurately as possible on a QWERTY keyboard. The ‘q’ key was pressed with the left index finger when the probe was presented at the upper location, and the ‘m’ key was pressed with the right index finger when the probe was presented at the lower location. Stickers showing up and down arrows were placed on the ‘q’ and ‘m’ keys respectively to help participants with responding. A new trial started after a response, or automatically when 2500 ms elapsed without response. When a participant responded erroneously, the term ‘error’ briefly appeared on the screen (200 ms). To reduce possible habituation to pain-related stimuli that might occur if all trials contained pain-related information, filler trials (neutral picture pairs presented for 100 ms (50%) or 1250 ms) were included. Further, in order to ensure that participants maintained gaze at the middle of the screen, a number of digit trials were presented (see e.g., [55; 62]). In these trials, the fixation cross was followed by a randomly selected digit between one and nine for a duration of 100 ms. Participants were instructed to type the number on the keyboard. Pictures were presented in randomized order across trials and participants. Trials were intermixed and randomly presented in 2 blocks, with a break between block 1 and block 2. For each participant, the target pictures as well as the probe were presented equally often at the top or bottom position of the screen in four possible combinations: target top/probe top; target top/probe bottom; target bottom/probe bottom; target bottom/probe top. Thus, the probe was equally likely to replace either a pain face or neutral face. In the context of the current study, *congruent* trials were those where the probe was presented at the same location as the pain face. *Incongruent* trials were those where the probe was presented at the same location as the neutral face. Each picture pair was presented 32 times. The inter-trial interval was 200 ms after picture trials, or 1100ms after digit trials to allow participants to place their fingers back on the ‘q’ and ‘m’ buttons. The task began with 16 practice trials consisting of neutral face-pairs, none of which appeared in the experimental trials. The test phase consisted of 192 test trials, 64 filler trials, and 18 digit trials. The dot-probe task was programmed and presented using the INQUISIT Millisecond software package (INQUISIT 2.0). INQUISIT measures reaction times (RTs) with millisecond accuracy (Inquisit 4.0; Millisecond Software, Seattle, WA, USA).

Split half reliability calculations indicated adequate internal consistency; Spearman-Brown Coefficients were .77 and .83 for attention bias indices at 100 ms and 1250 ms, respectively.

2.5 Procedure

Upon arrival, participants were allocated participant numbers and then completed the informed consent form. Participants were informed that they would first complete a computer task, and afterwards would be asked to fill out some questionnaires using an online format. Participants were seated in front of a computer at a distance of approximately 60 cm from the screen. Instructions for the dot-probe task were presented on the computer screen. Participants were informed that they would see several pictures of individuals undergoing a painful procedure. The experimenter watched the participant whilst s/he performed practice trials to ensure that s/he understood the instructions. Participants were given the following instructions: "During this computer task, a white cross will be shown at the centre of the screen. Try to focus your eyes on this cross when it appears. After the white cross appears, two pictures of people will be shown. One picture will be shown at the top of the screen, one picture will be shown at the bottom of the screen. Immediately after the pictures are shown, a small white square will appear where one of the pictures was (i.e., at the top or bottom part of the screen). Your task is to indicate, using two keys on the keyboard, as fast as possible, where you have seen the square. Press 'Q' when you have seen the square at the upper part of the screen. Press 'M' when you have seen the square at the bottom part of the screen. Try to be as fast and accurate as possible. Sometimes, a number will be shown at the location of the white cross. When this happens, you have to type this number using the keyboard. Try to make as few errors as possible." Participants were also informed that there would be a break in the middle of the computer task, and that they should take around 1 minute to silently look away from the computer screen. After completing the dot-probe task, participants completed the questionnaires. Upon completion, participants were debriefed as to the nature of the study, and given a £5 Amazon voucher.

2.6 Data reduction and statistical plan

To investigate *the relationship between adolescent pain catastrophizing and selective attention to pain* (i.e., hypothesis 1), mean reaction times (RT) on congruent and incongruent trials were used as dependent variables in the analyses. Analyses employed a 2 × 2 factorial repeated measures design with congruency (congruent / incongruent) and presentation time (100 ms / 1250 ms) as within subject factors and adolescent centered pain catastrophizing score entered as a covariate. Repeated measures ANOVA was chosen since the design of our study include presentation time as a within-subjects variable and we were interested in whether the effects of pain catastrophizing and selective attention to pain varied across presentation times. Pain catastrophizing was entered as a covariate in order to retain the full range of scores on this continuous measure, rather than arbitrarily splitting participants into groups, thereby retaining greater variance to observe relationships. In case of a significant catastrophizing x congruency interaction, attention bias indices were calculated to ease interpretation of the direction of differences between congruent and incongruent trials, and Pearson correlation analyses were performed to examine their relationship with catastrophizing. Bias scores were calculated by subtracting the average detection time on congruent trials from the average detection time on incongruent trials. A positive bias index indicates increased selective attention to pain faces, whereas a negative index is indicative of attentional avoidance. A mean bias index (across 100 ms and 1250 ms) was calculated in case the congruency x catastrophizing x presentation time three-way interaction did not reach significance, whereas separate bias indices were calculated for 100 ms and 1250 ms and used within separate analyses in case the three-way interaction also reached significance.

For all analyses, the cutoff for statistical significance was set at $p < .05$, and effect sizes were reported using the Partial Eta Squared index (ηp^2). Following Cohen [9] and Olejnik and Algina [39]; small effect size = 0.01; medium effect size = 0.06; large effect size = 0.14.

To investigate *the potential moderating role of attention control on the relationship between adolescent pain catastrophizing and selective attention to pain* (i.e., hypothesis 2), analyses were re-run but with the centered attention control score also entered as a covariate. Again a repeated measures ANOVA was selected in order to reflect the within-subject variable of presentation time, which could moderate the effects of our key variables. In case of a significant catastrophizing x congruency x attention control three-way interaction, additional moderation analyses were performed to interpret interaction effects (i.e., whether the association between the predictor variable (pain catastrophizing) and the outcome (attention bias) is significant only for high levels of the moderator variable (attention control), low levels of the moderator variable, or both). Moderation analyses followed the procedure outlined by Holmbeck [24]. To this end, two steps were performed. First, two new conditional continuous moderator variables were computed by (1) subtracting 1 SD from the centered moderator variable (high levels of adolescent attention control) and (2) adding 1 SD to the centered moderator variable (low levels of adolescent attention control). Next, two additional ANCOVAs were performed - incorporating each of these new conditional continuous moderator variables - to test the significance for low (1 <u>SD</u> below the mean) and high (1 <u>SD</u> above the mean) values of the conditional moderator variable. In case of significant three way interactions including presentation time, congruency, and <u>one</u> of the continuous variables (ie., either attention control or pain catastrophizing), we calculated separate correlation analyses between the continuous variables and the attention bias indices (i.e., attention bias at 100 ms and attention bias at 1250 ms) to ease interpretation of direction of effects (see [30] for similar procedure). In case the four-way interaction (i.e., including presentation time) also reached significance, these analyses were performed separately for 100 ms and 1250 ms, otherwise the average bias index (across 100 ms and 1250 ms) was used. In all analyses, Greenhouse-Geisser corrections (with adjusted degrees of freedom, or NDf) were performed whenever the sphericity assumption was violated (Mauchly's test of sphericity was $p < .05$).

3. RESULTS

3.1 Participant characteristics

The mean level of adolescents' pain catastrophizing was 21.62 (SD = 11.03), and the mean level of attention control was 47.15 (SD = 8.51). Girls reported significantly higher levels of pain catastrophizing thoughts compared to boys ($t(71) = -2.01$, *p* □ .05, $d = .48$), but did not differ on the measure of attention control ($t(71) = 1.49$, ns, $d = .35$). Pain catastrophizing was significantly negatively correlated with attention control ($r = -.26$, *p* □ .05). No significant correlations were observed with child age (both $r \leq .21$, ns).

3.2 Attention bias analyses

3.2.1 Data preparation

Consistent with previous research [55; 58; 62], trials with errors and responses shorter than 200 ms or longer than 2000 ms were discarded. Within the present sample, the number of errors made by participants ranged from 0 to 24 (M= 5.73), and .05% of the RTs fell outside the 200ms – 2000ms range. Probe detection latencies that were three standard deviations above or below the individual mean reaction time of corrected responses were also considered outliers and excluded from analyses (see [30; 58; 62]). This was the case for 1.43% of the RTs. Statistical analyses were run on 96.34% of the data.

3.2.2 The relationship between adolescent pain catastrophizing and selective attention to pain

Mean RTs and SDs on different trial types are presented in Table 1. The RTs were analysed using a 2 (congruency: congruent / incongruent) x 2 (presentation time: 100 ms / 1250 ms) repeated measures analysis of variance (ANCOVA) with pain catastrophizing entered as a covariate. Analyses revealed no main effect of congruency ($F(1,71) = .27$, ns, $\eta p^2 = .004$), indicating no overall selective attention to pain. Likewise, there was also no significant effect of catastrophizing ($F(1,71) = .50$, ns, $\eta p^2 = .007$) or presentation time ($F(1,71) = 2.88$, ns, $\eta p^2 = .039$), nor were there any significant two or three way interactions (all $F \leq .88$, ns, all $\eta p^2 \leq .012$), indicating that attention deployment to either pain or neutral faces did not depend upon adolescents' level of pain catastrophizing, presentation time (i.e., 100 ms / 1250 ms), or the interaction between both.

-INSERT TABLE 1 HERE-

3.2.3. The moderating role of attention control in the relationship between adolescent pain catastrophizing and selective attention to pain

To investigate the moderating role of attention control, a similar repeated measures ANCOVA was run but with the centered attention control score also entered as a covariate. Analyses revealed a significant three-way interaction of pain catastrophizing with congruency and attention control ($F(1,69) = 4.55$, $p < .05$, $\eta p^2 = .062$), indicating that the relationship between pain catastrophizing and attention bias to pain is dependent upon levels of attention control. Furthermore, there was also a significant attention control x congruency x presentation time interaction ($F(1,69) = 4.26$, $p < .05$, $\eta p^2 = .058$), indicating that the relationship between attention control and attention bias to pain varies with different presentation times (100 ms / 1250 ms). No other main or interaction effects were observed (all $F \leq 3.75$, ns, all $\eta p^2 \leq .051$). Below, we first report on the three-way interaction between pain catastrophizing, congruency, and attention control, and we then report on the three-way interaction between attention control, congruency, and presentation time.

To interpret the significant pain catastrophizing x congruency x attention control interaction, two univariate ANOVAs were performed with the average bias index (i.e., across 100 ms and 1250 ms) entered as the dependent variable, pain catastrophizing as the predictor variable, and high (1SD above the mean) or low (1SD below the mean) values of self-reported attention control as a covariate. As shown in Figure 1, findings indicated a cross-over interaction, indicating that pain catastrophizing differentially impacted attention bias to pain dependent upon high vs. low levels of adolescents' attention control. Specifically, for adolescents reporting *high* levels of attention control, pain catastrophizing was negatively associated with attention to pain. Conversely, for adolescents reporting *low* levels of attention control, pain catastrophizing was positively associated with attention to pain. While these patterns did not significantly differ from 0 for adolescents reporting low attention control ($F(1,69) = 1.13$, ns, $\eta p^2 = .016$) and only approached significance for adolescents reporting high attention control ($F(1,69) = 3.31$, $p = .07$, $\eta p^2 = .046$), the significant cross-over interaction indicates these patterns are significantly different from each other. Inspection of Figure 1 also suggests that attention control affects attention bias to pain differently for high catastrophizing adolescents relative to low catastrophizing adolescents. Indeed, additional analyses *within high catastrophizing* adolescents showed that attention control was negatively associated with attention bias to pain such that lower levels of attention control were associated with increasing attention bias towards pain ($F(1,69) = 5.96$, $p < .05$, $\eta p^2 = .08$). Attention control was not associated with attention bias to pain for low catastrophizing adolescents ($F(1,69) = .52$, ns, $\eta p^2 = .007$). Re-running analyses whilst also controlling for adolescent gender revealed similar main effects and interactions between pain catastrophizing x congruency x attention control and attention control x congruency x presentation time, with no additional significant terms involving gender.

To interpret the significant attention control x congruency x presentation time interaction, which indicates that the relationship between attention control and attention bias to pain varies with different presentation times, separate Pearson correlation coefficients were calculated between adolescents' attention control score and the attention bias index at 100 ms and 1250 ms, respectively. Findings indicated attention control was significantly negatively correlated with the attention bias index at 1250 ms (r = -.24, p □ .05). No significant correlation was observed for the attention bias index at 100 ms (r = .05, ns).

-INSERT FIGURE 1 HERE-

4. DISCUSSION

In this study, we used a dot-probe methodology to investigate the relationship between pain catastrophizing and attention bias to facial expressions of pain in a non-clinical sample of adolescents. We further investigated the moderating role of self-reported attention control. We hypothesised that (1) adolescents' level of pain catastrophizing would be associated positively with an attention bias towards pain faces, and (2) based on a dual process model of pain, that adolescents' self-reported attention control would moderate the association between pain catastrophizing and attention bias to pain faces. Results partially supported our hypotheses. We found that while there was no main effect of pain catastrophizing on attention bias towards pain, attention control did significantly moderate this relationship. Specifically, we found a cross-over interaction indicating that whereas pain catastrophizing was negatively associated with attention bias to pain among adolescents reporting high attention control, the opposite pattern was observed among adolescents reporting low attention control. While separate analyses examining effects at low and high attention control did not reach significance, the observed cross-over interaction suggests, in line with expectations, that low levels of attention control are particularly relevant in understanding increasing attention to pain stimuli among high pain catastrophizing adolescents. Indeed, additional analyses indicated that lower levels of attention control were significantly associated with increasing attentional vigilance towards pain faces only within high catastrophizing adolescents. No such pattern was observed among low catastrophizing adolescents. In addition, we found that poorer attention control was related to increased attention bias for pain faces (regardless of pain catastrophizing level) when these faces were presented for relatively longer durations (i.e., 1250 ms), but not for short durations (i.e., 100 ms).

To our knowledge, this is the first study to examine the relationship between attention bias toward pain-related information, level of attentional control, and individual differences in catastrophic beliefs about pain and its consequences. The study was cast within and supports a dual process model of attentional processes in pain. Broadly, dual process models provide an account of how phenomena occur from both implicit and explicit processes, and this theoretical framework has been important in furthering our understanding of a range of clinical disorders. For example, adult [2; 16; 25; 42] and paediatric [22; 50] studies have demonstrated a moderating effect of attention control on the relationship between *anxiety-related* variables (e.g., trait and state anxiety, post-traumatic stress symptoms) and attention bias to threat. Our study replicates these previous findings within the psychopathology literature but extending them to the study of pain. Specifically, our findings suggest that both automatic and controlled attentional processes are important in the relationship between attention to pain and pain cognitions. As such, these findings can help to explain why some studies find positive associations between pain catastrophizing and attention bias [28; 51; 57], whilst others find negative or no associations [6; 58; 59]. Our findings may also have implications for the literature on Attention Bias Modification (ABM), a training technique which aims to target and shift attention biases – possibly by enhancing attention control. These ABM techniques have been employed most often in the anxiety and depression literatures, but are now starting to be employed within the adult pain literature [44; 45]. Although not definitive, there is some suggestive data that ABM may increase attention control, rather than shift biases per se. Our findings indeed suggest that attention control may play an important role in the association between pain catastrophising and attention bias, perhaps allowing individuals to subsequently disengage from pain-related threat.

This study also extends the limited paediatric literature examining attention biases within the context of pain. Indeed, only four published studies to date have investigated attention bias to pain-related information in youth [4; 7; 53; 62], and only one within the context of pain catastrophizing [62]. This dearth of research is surprising, given the significant number of children suffering from (chronic) pain [29], the hypothesized pivotal role of attention in the development and maintenance of pain problems [1; 17; 52; 63], the importance of pain catastrophizing in understanding deleterious pain outcomes (e.g., increased pain/disability) among both clinical and nonclinical paediatric samples [11; 31; 60], and the need for novel treatment approaches targeting anxiety-related factors in paediatric chronic pain patients [21]. Furthermore, given neuroimaging and behavioural evidence [5; 10; 36] that brain areas underlying executive functions such as attention control are still developing during adolescence, the examination of attention control as a moderating factor on the association between pain catastrophizing and attention bias to pain-related stimuli may be particularly important within adolescence. Samples spanning childhood, adolescence, and adulthood will be important to examine whether and at what point in child development these associations are most stable.

The present study is also one of few studies (see also [3]) to explore attentional capture by pain temporally (i.e., at 100 ms and 1250 ms stimulus presentation times), and is the first study to do so with adolescents. Our analysis yielded an additional interaction between attention control, congruency, and presentation time, suggesting that the relationship between attention control and attention bias to pain faces varies at early and later stages of processing. Specifically, adolescents high in attention control selectively avoided pain faces at longer (1250 ms) but not shorter (100 ms) presentation times. This is perhaps unsurprising, given the inherently aversive nature of pain facial expressions [8], and the fact that 1250 ms (but not 100 ms) is arguably enough time to exert effortful attentional control to shift away from aversive stimuli. Importantly, while our results may at first seem different to a recent meta-analysis revealing a more pronounced attention bias *towards* pain-related information when stimuli were presented for 1250 ms [43], this is not necessarily the case, as the studies included in the meta-analysis did not specifically investigate whether associations varied with attention control. Furthermore, the current study comprised healthy adolescents, whereas the meta-analysis included only adults with chronic pain, so one cannot generalize those findings to the findings presented here. Interestingly, though, we found no effect of presentation time on the association between pain catastrophizing and attention control in predicting attention bias (as indicated by a non-significant four-way interaction), indicating that attention control moderates the association between pain catastrophizing and both early and later attentional capture by pain stimuli in a similar way. It will be important for future studies to replicate our findings and to examine the efficacy of briefly presented stimuli (i.e., 100 ms) to capture attention in youth. Future studies may also benefit from using new technologies such as eye-tracking (see e.g., [61]) to further reveal the temporal nature of this relationship. Eye-tracking technologies could supplement dot-probe methodology used in this study by providing continuous indices of the focal point of attention, allowing precise examination of the temporal dynamics of selective attention in youth, and by overcoming issues of reliability reported in previous dot-probe tasks [14].

This study has limitations. First, most of our sample is female. Second, we used a community sample of healthy adolescents, and did not collect detailed information regarding pain history. We simply relied on a brief screening with teachers to exclude participants who were suffering from chronic pain. Given epidemiological findings, we would expect some individuals to experience recurrent pain even within community samples, and these pain experiences would likely also impact our findings. Third, all threat detection studies rely on salient cue stimuli. Whilst faces are more relevant than words, they limit us to general effects that are not specific to individual participants. Future studies may benefit from using age-appropriate faces, and by increasing personal salience such that pain faces cue a potential personal pain experience (see e.g., [62]). Fourth, we used a single, self-report measure of attention control. Whilst the ACS has shown good utility in predicting attentional performance in behavioural tasks [16], it will be important for future studies to also include experimental measures of attention control such as flanker tasks (that are reliant on behavioural responses and reaction times) as well as an antisaccade task (that is reliant on eye movement patterns) (e.g., [19; 20; 27]). These measures may be particularly important in child and adolescent samples, as attention control is still changing during this period, and may be more difficult to accurately self report. Furthermore, whilst the ACS assesses an individual's general capacity to focus in the face of distraction and to shift attention, these general capacities may differ from the ability to control attention in pain-specific contexts. In particular, individuals high in pain catastrophising may exhibit more difficulties in attention control in pain than non-pain contexts. The fact that we find a significant moderation effect of general attention control attests to the importance of this general capacity in influencing pain-specific constructs, however examining attention control also within the context of pain may be useful for furthering our understanding of this effect. Finally, this study is cross-sectional, so causal hypotheses are untested. Whilst pain catastrophizing may indeed impact attention bias to pain, the reverse may also be true. Indeed, according to a dual process framework, the interaction between attention bias and attention control may be particularly useful in *predicting pain catastrophizing*. Specifically, given the hypothesized causal role of attention bias in the development and maintenance of chronic pain problems [40; 63], and the possibility of using attention bias modification techniques for prevention and intervention strategies [15; 44], future studies employing longitudinal and training designs to investigate the dynamic interplay between attention biases, attention control, and pain catastrophizing will be particularly valuable.

The current findings extend our understanding of the attentional functioning of adolescents with varying levels of pain catastrophizing. Specifically, findings attest to the importance of examining attention control as a moderating variable on the association between pain catastrophizing and attention bias to pain, thus advancing theory and informing potential interventions.

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FIGURE LEGENDS

Figure 1: Average bias indices for pain faces as a function of low (1SD below the mean) and high (1SD above the mean) levels of adolescents' attention control *$p < .05$; (*)$p < .10$

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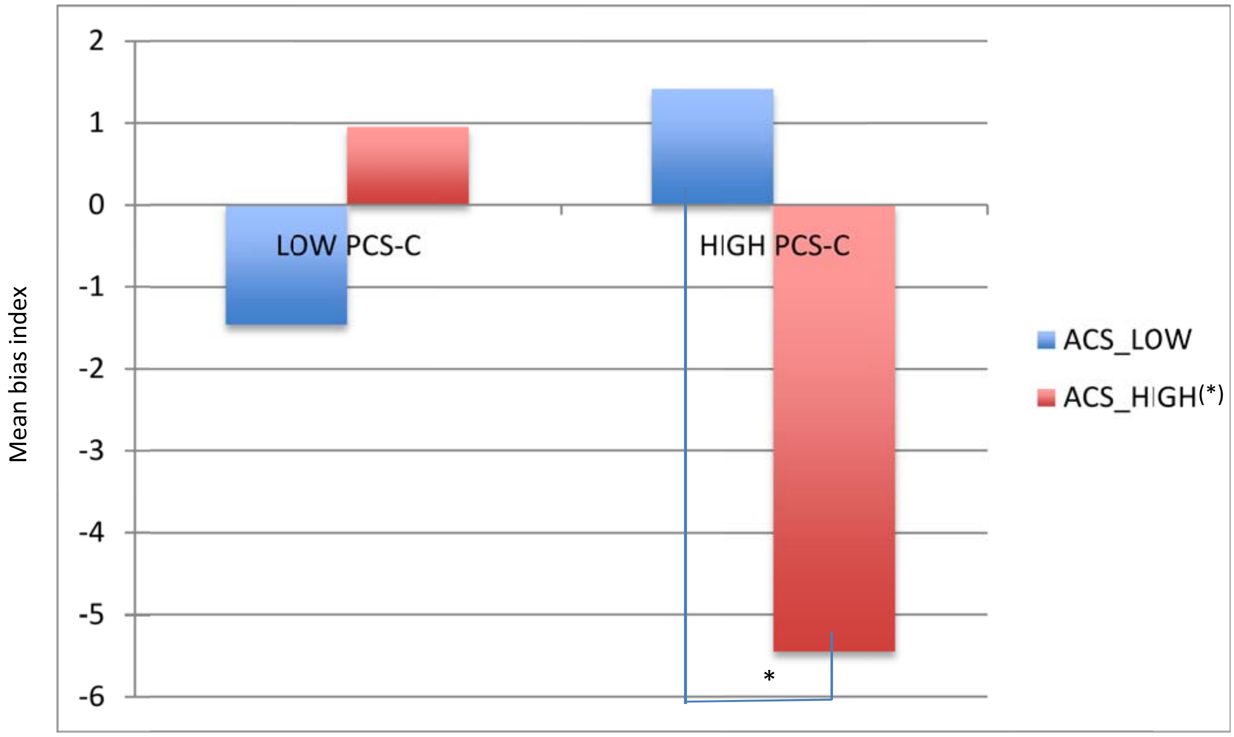

Mean bias index
2
1
0
-1
-2
-3
-4
-5
-6
LOW PCS-C
HIGH PCS-C
*
ACS_LOW
ACS_HIGH(*)

Table 1: Mean reaction times (in milliseconds) and standard deviations (SD) on congruent and incongruent trials for 100 ms and 1250 ms presentation time

	Congruent trials	Incongruent trials
100 ms	454 (55)	453 (53)
1250 ms	458 (53)	459 (56)